Platform and Environmental Effects on Above-Water Determinations of Water-Leaving Radiances

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ABSTRACT

A comparison of above- and in-water spectral measurements in Case-1 conditions showed the uncertainty in above-water determinations of water-leaving radiances depended on the pointing angle of the above-water instruments with respect to the side of the ship. Two above-water data processing methods were used to create a diagnostic variable (formulated for Case-1 waters only) to quantify the presence of superstructure reflections that degraded the above-water intracomparisons of water-leaving radiances by as much as 13%–27% (for far-to-near viewing distances, respectively). The primary conclusions of the above- and in-water intercomparison of water-leaving radiances were as follows: (a) the SeaWiFS 5% radiometric objective was achieved with the in-water instruments; (b) the above-water approach produced agreement to within 5%, but reliably for about half the data, and only with well-controlled procedures and severe filtering to remove glint contamination; (c) a decrease in water-leaving radiance values was seen in the presence of swell, although, wave crests were radiometrically brighter than the troughs; and (d) standard band ratios used in ocean color algorithms remained severely affected, because of the relatively low signal at 555 nm and, thus, proportionally significant ship contamination at this wavelength. Suggestions for a more precise above-water measurement protocol are tentatively proposed.

1. Introduction

Ocean color satellite sensors (IOCCG 1998) provide large-scale synoptic observations of biogeochemical properties of the upper layer in the open ocean (e.g., phytoplankton biomass), as well as continuous monitoring of other important parameters in the coastal zones (e.g., sediment load and dissolved colored matter). This global capability is accomplished through the determination of radiometric quantities, specifically, the spectral values of the radiances at the top of the atmosphere from which (after atmospheric correction) the spectral radiances emerging from the ocean surface, $L_W(\lambda)$, are extracted (λ denotes the wavelength).

For meaningful applications, an extremely high radiometric accuracy is required. For example, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS)[1] Project requires accuracies of 5% absolute and 1% relative in terms of the retrieved $L_W(\lambda)$ values (Hooker and Esaias 1993).[2] The first obvious condition for reaching such an accuracy lies in the conception and the realization of the spaceborne instrument. Although this is a necessary requirement, it is not sufficient to ensure the distributed radiometric data meet the accuracy objectives. Indeed, the success of any ocean color mission is determined in particular by the quality of the optical dataset collected for calibration and validation purposes, and involves several continuous activities (Hooker and McClain 2000): (a) characterizing and calibrating the sensor system, (b) analyzing trends and anomalies in the sensor performance and derived products (the L_W values and the chlorophyll concentration), (c) supporting the development and validation of algorithms (for the retrieval of bio-optical properties and for atmospheric correction), and (d) verifying the processing code and selecting ancillary data (e.g., ozone, wind, and atmospheric pressure) used in the data processing scheme.

This paper does not deal with all aspects of the calibration and validation process. It is restricted to those field measurements suitable for vicarious calibration, as well as the derivation or improvement of bio-optical algorithms. Historically, the fundamental radiometric quantities selected for comparison with the radiances measured by—or, more precisely, retrieved from—the

[1] See appendix A for glossary of terms.

[2] See appendix B for list of primary symbols.

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spaceborne sensor were the upwelled spectral radiances just above the sea surface, $L_W(\lambda, 0^+)$ (the symbol 0^+ means immediately above the surface).

The $L_W(\lambda, 0^+)$ radiances can be derived by extrapolating in-water measurements taken close to the sea surface or obtained directly from above-water measurements. In-water techniques have been largely successful in Case-1 waters, but the above-water approach for vicarious calibration remains nevertheless attractive, because (a) the data can presumably be collected more rapidly and from a ship underway, and (b) the frequently turbid and strongly absorbing waters in shallow Case-2 environments impose severe limitations on in-water measurements, particularly because of the instrument self-shading effect. For both methods, protocols have been recommended (Mueller and Austin 1992) and revised (Mueller and Austin 1995; Mueller 2000a,b).

From a measurement perspective, the above-water problem is more restrictive, because presently there is no reliable mechanism for floating an above-water system away from a ship (which is easily and effectively accomplished for an in-water system), so all above-water measurements are made in close proximity to the vessel. The objective of the present study, based on high quality data collected during a one-month field campaign in Case-1 waters under excellent sky and sea-state conditions, is to compare both techniques in various geometrical conditions (pointing angles plus sun and ship positions), and to examine several problems associated with above-water determinations, particularly those caused by perturbations from the ship itself and other environmental factors, such as oceanic swell.

7. Conclusions

Although in-water measurements have successfully been used for deriving water-leaving radiances and validating ocean color sensors, above-water measurements form an alternative, which remain to be comparatively evaluated. This was the first objective of this study, while the second one was to quantify the perturbations due to the sampling platform and environmental conditions on the above-water measurements.

Two independent, but intercalibrated, profiling instrument systems provided the same results (within 2%) in terms of $L_W(\lambda)$, and satisfied the radiometric requirements under all conditions. The measurements were carried out in clear Case-1 waters under mostly cloud-free skies, so the extrapolation procedures were accurate and not degraded by instrument self-shading uncertainties. These $L_W(\lambda)$ values can safely be (and were) used as reference values, to which the results of the above-water determinations, once corrected for the bidirectional dependency, were compared. This approach permitted the biases possibly affecting the latter to be discerned.

To the extent that sun glint does not contaminate the above-water data, accomplished here using a high rejection rate (95%) of the brightest recorded data, removing the skylight reflection, or other kinds of reflections, is the major problem when processing the above-water measurements. In spite of very good conditions in general, considerable effort, and a large number of sampling opportunities, the desired agreement between the above-water $L_W(\lambda)$ values and the in-water reference values (within $\pm 5\%$) was only achieved approximately half the time, and only for the Q95 method. Unfortunately, the band-ratio results for the latter were significantly degraded by the ship perturbation effect and were rendered useless for most bio-optical applications.

Considering the flaws already identified when using above-water methods (O'Reilly et al. 1998; Fougnie et al. 1999), this rather low rate of success is not surprising, albeit somewhat discouraging, particularly when considering that more adverse (sea and sky) conditions are common. In rough sea states (without foam, however), the swell and its orientation are another source of inaccuracies not yet understood.

With *Thalassa*, the ship shadow and the hull albedo effects were significantly smaller than, and appeared mostly inseparable from, the perturbation related to the superstructure albedo. The main source of discrepancy between the above- and in-water determinations of water-leaving radiances originates from the additional reflection by the ship's superstructure, which is generally poorly quantified, if not simply ignored. The use of two methods (S95 and M80) when processing the above-water data allowed the presence of this perturbation to be detected using a *diagnostic parameter*, the $r(865)$ ratio, and its departure from unity established the degree of contamination.

This ratio was found to be close to unity in only a few occurrences (Figs. 5 and 6), which means superstructure contamination was the general rule in the present above-water measurements, and was considerable in some instances. Deriving this diagnostic parameter is an easy way to detect the presence of such contaminations (as well as any other unexpected contamination by any source brighter than the water itself), and this method can be recommended in Case-1 waters (and likely in dark Case-2 waters dominated by yellow substance). Indeed, in Case-1 waters $L_W(865)$ is about two orders of magnitude below the water-leaving radiances within the visible part of the spectrum (Fig. 3; Siegel et al. 2000), thus the quantity $L_T(865)$ can safely be considered as exempt from any marine signal (not true in Case-2 waters dominated by sediment).

Another perturbation possibly influencing the $r(865)$ value deserves examination. The portion of the sky sampled by a wave-roughened sea surface dramatically widens with increasing wind speed (Mobley 1999; Toole et al. 2000). This widening, however, does not affect the $r(865)$ parameter if the portion of the sky remains homogeneous (i.e., does not contain bright clouds not seen by the narrow angle sensor used to measure L_{sky}). To ensure the robustness of $r(865)$ as a diagnostic parameter, this experimental constraint must be respected. The choice of a correct value for ρ accounting for the actual wind speed (Mobley 1999) is also a requirement to preserve the significance of $r(865)$.

Avoiding this ship contamination cannot be achieved through the use of polarizing systems, because its angular origin differs from that of the reflected sky radiation (and of the Brewster incidence angle).